Recent Model Development Activities at GFDL

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Outline

1. GFDL latest climate models AM/CM4;
    - ❖ Mean climate
    - ❖ Tropical variability (weather)

2. Use of satellite simulator: success and challenges;

3. Thoughts on future model development.

Family tree of recent GFDL models

CMIP3
Previous generation
circa 2004-2006

CM2
interactive clouds,
prescribed aerosols/ozone,
aerosol-radiation interactions

CMIP5
Current generation
circa 2009-2011

CM3
interactive aerosols/ozone,
coupled trop.-strat. chemistry,
aerosol-cloud interactions

FLOR, HIFLOR
seasonal-decadal forecast model
CM2.5, CM2.6
high-res. coupled models
HiRAM
high-res. atmosphere model
ESM2-M, ESM2-G
earth system models

CMIP6
Next generation
circa 2014-2017

CM4/ESM4
higher resolutions (50/100 km),
updated physics,
physical climate model
and ESM built simultaneously

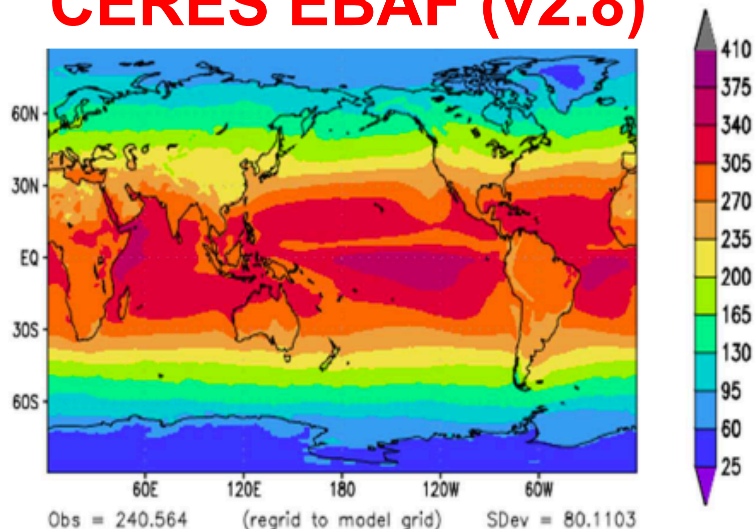
A status report on CM4

- **FV3 (cubed-sphere, finite-volume) dynamical core** (S.J. Lin)
- **50 or 100 km horizontal resolution, ~32 or 48 vertical layers**
- **A new double-plume convection (DPC) scheme** (M. Zhao)
  - Based on the single bulk plume model used in HiRAM (Bretherton et al., 2004)
  - Additional (deep) plume with entrainment dependent on ambient RH
  - Use quasi-equilibrium cloud work function for closure
  - Cold-pool driven convective gustiness via precipitation re-evaporation
  - Motivated by recent literature and MJO simulation
- **“Light” aerosols/chemistry or “full” aerosols/chemistry**
- **MOM6 being built** (A. Adcroft, R. Hallberg)
  - ¼ degree as the primary target
  - Mesoscale eddy parameterizations
  - New mixed layer scheme

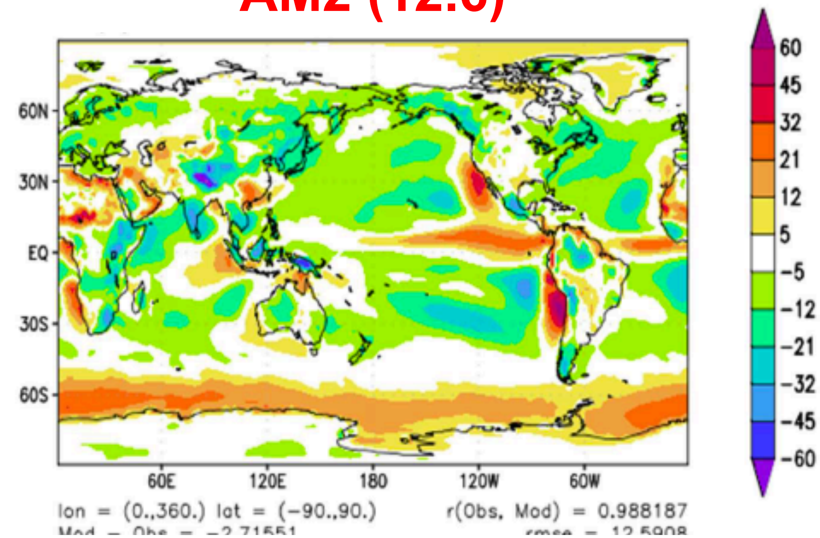
Mean climate simulation

TOA SW radiation (W m^{-2})

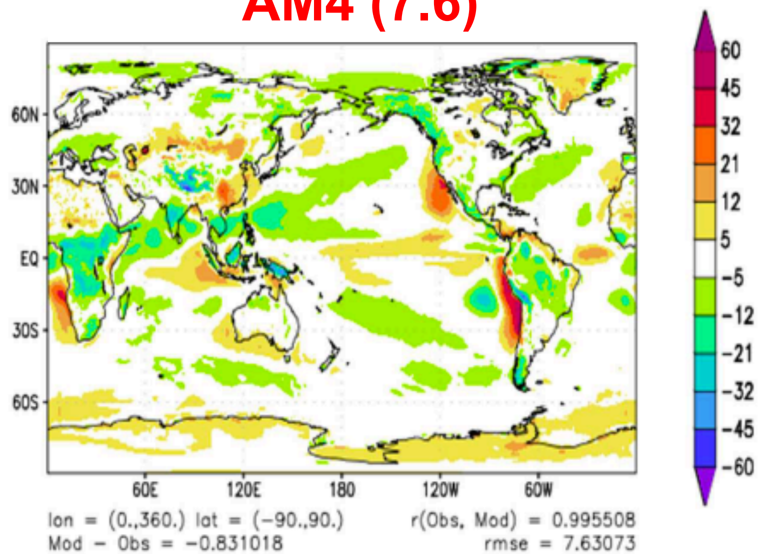
CERES EBAF (v2.8)



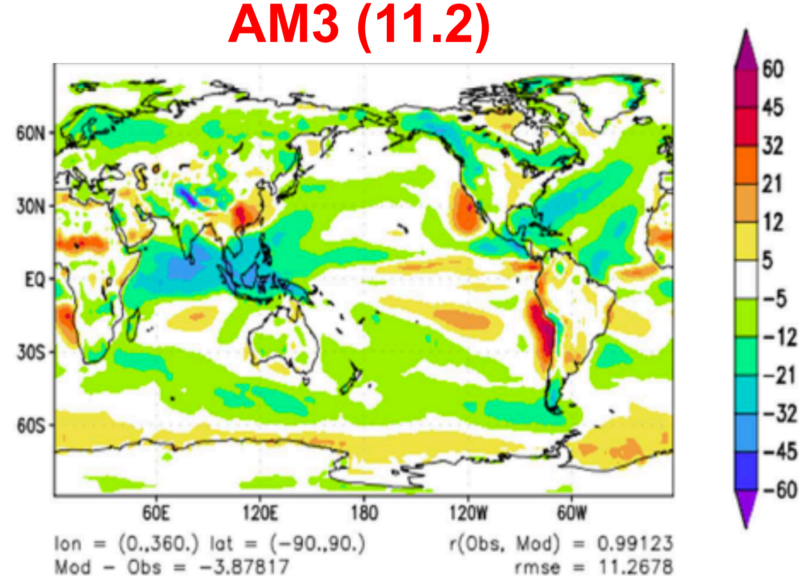
AM2 (12.6)



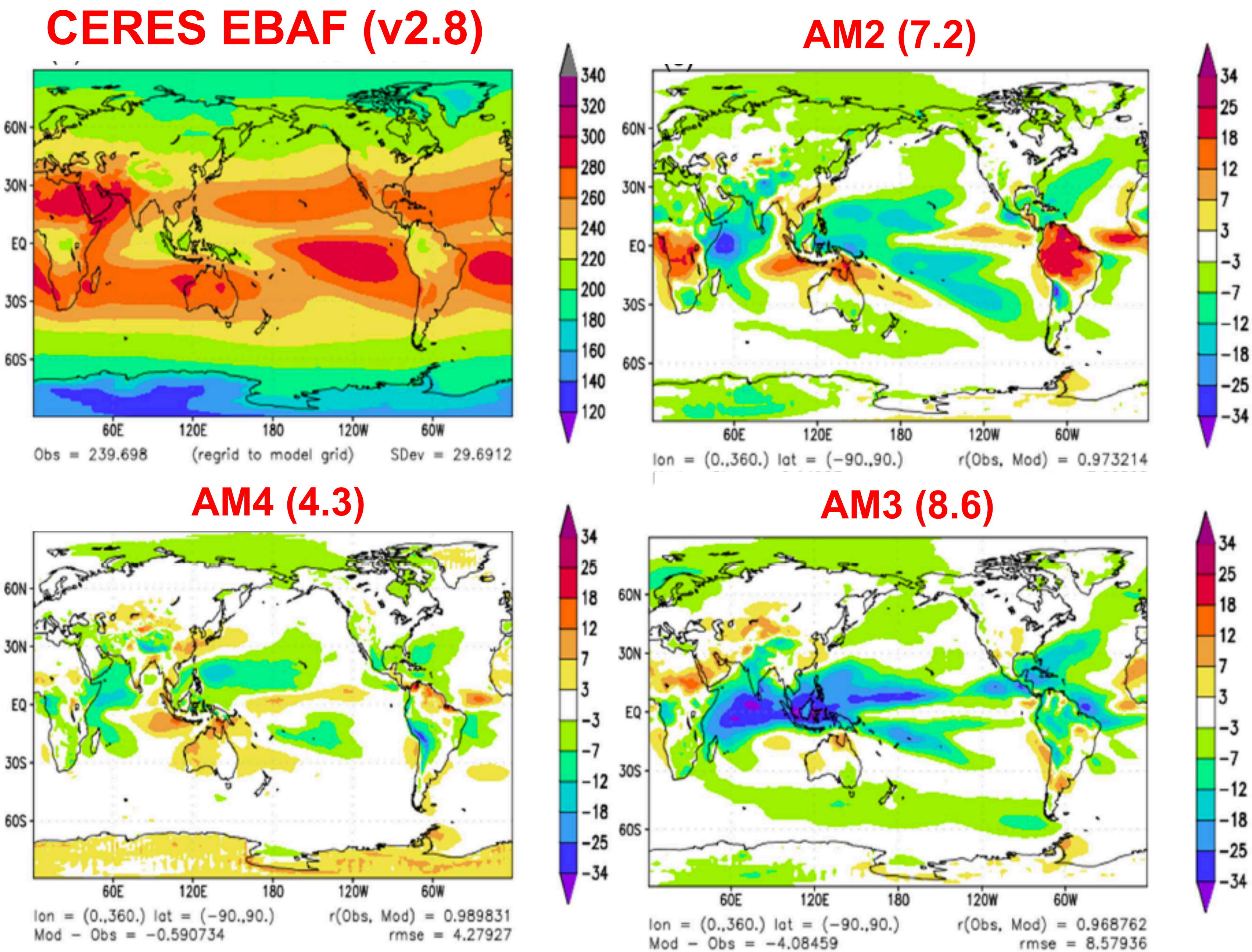
AM4 (7.6)



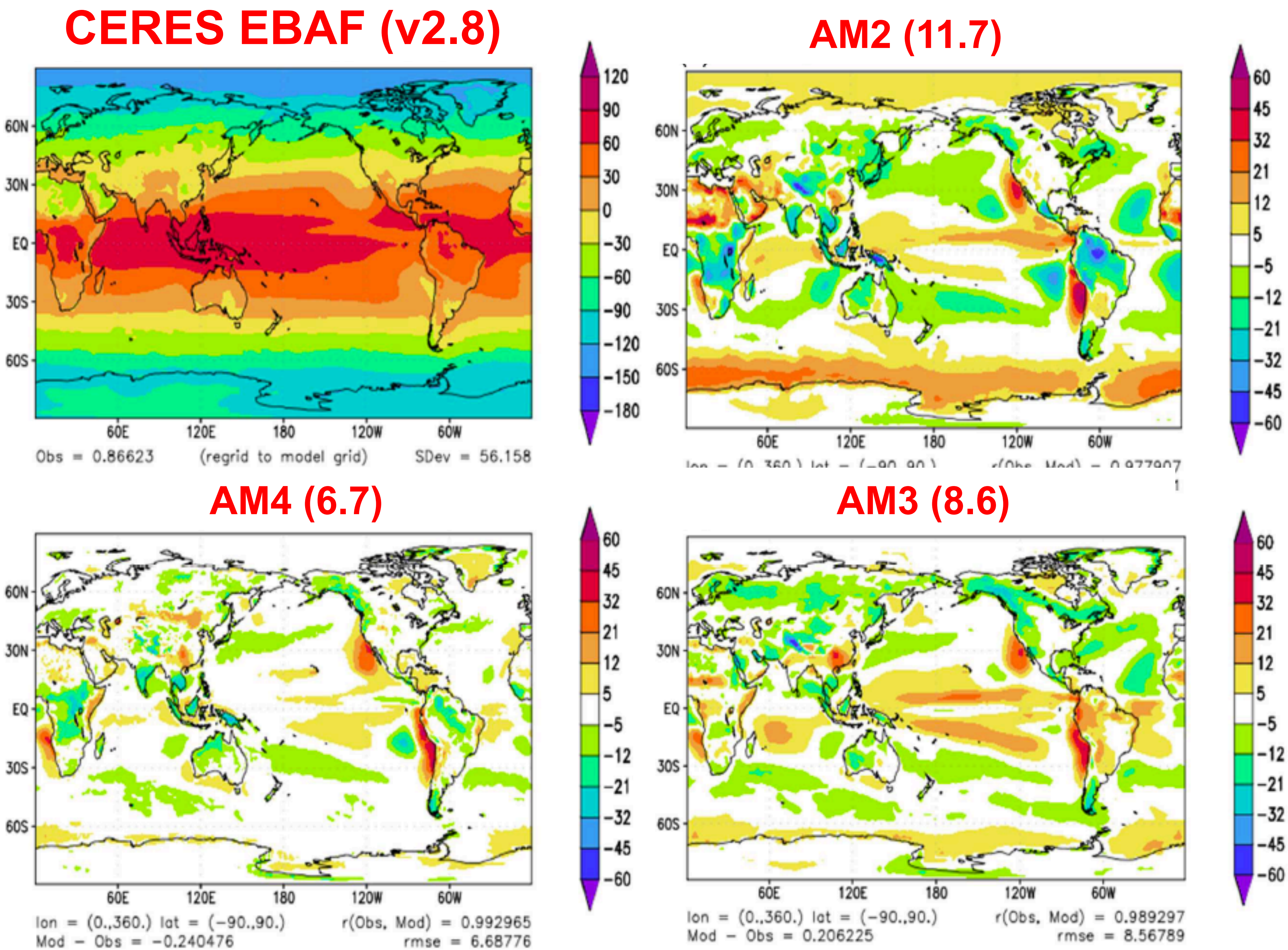
AM3 (11.2)



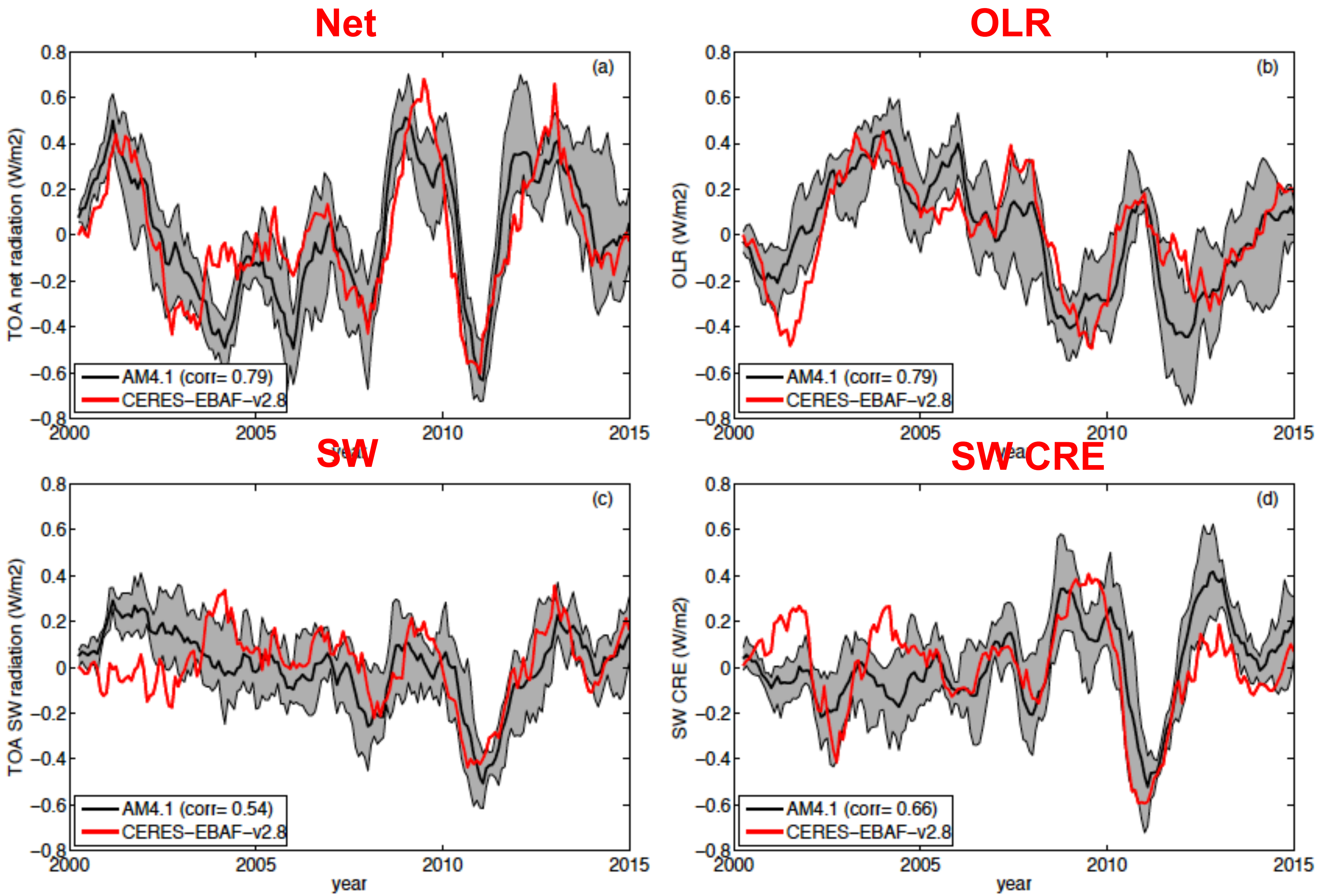
Outgoing LW radiation (OLR) (W m^{-2})



TOA net radiation (W m^{-2})

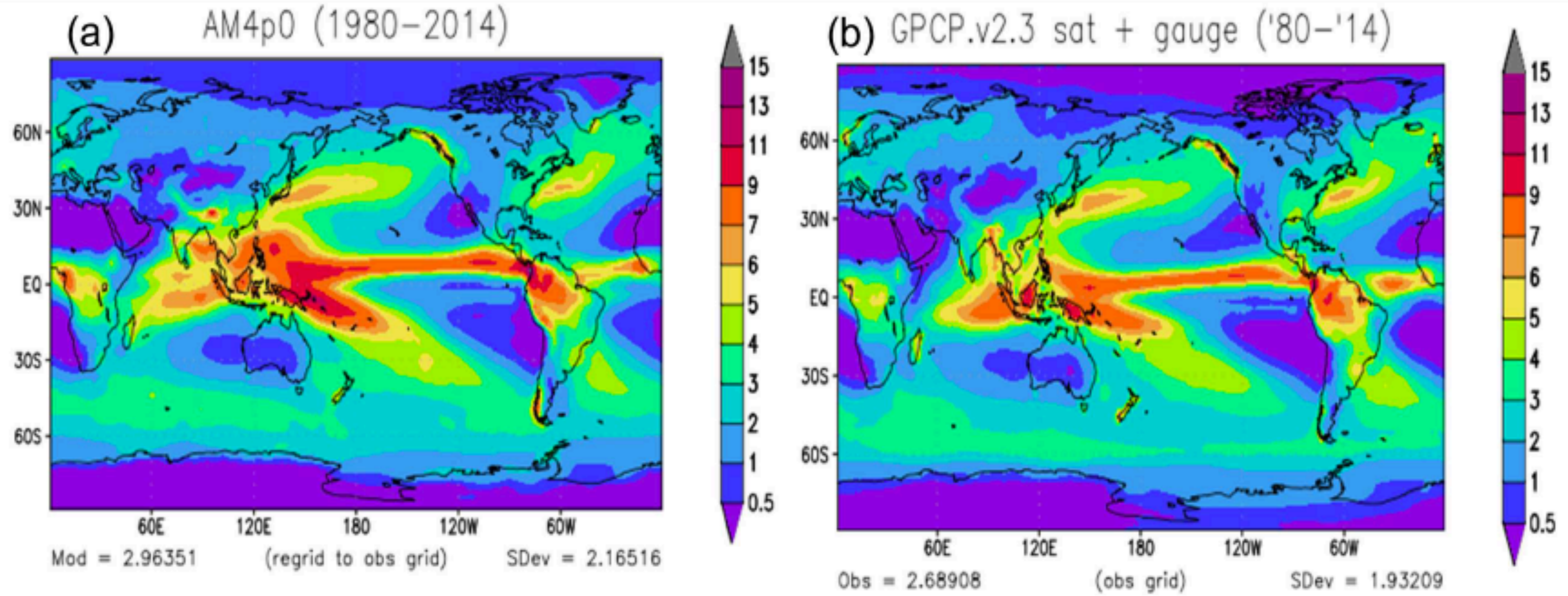


Deseasonalized time series of TOA radiation (W m^{-2})



Precipitation (mm day^{-1})

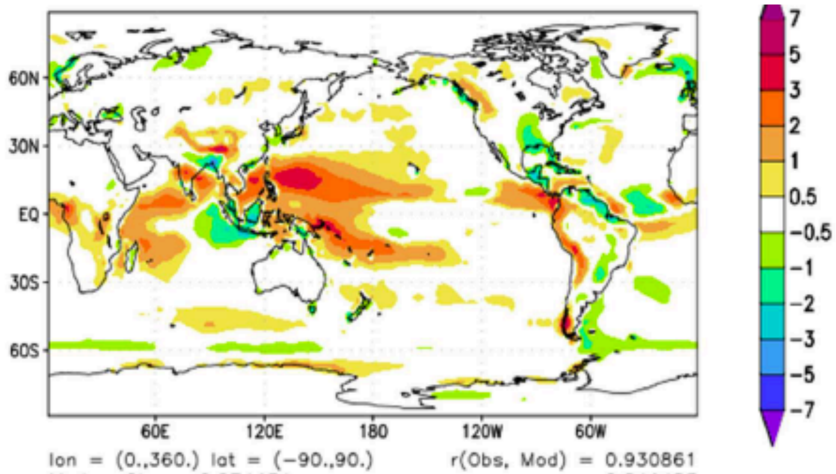
AM4 (3.0) **GPCP (2.7)**



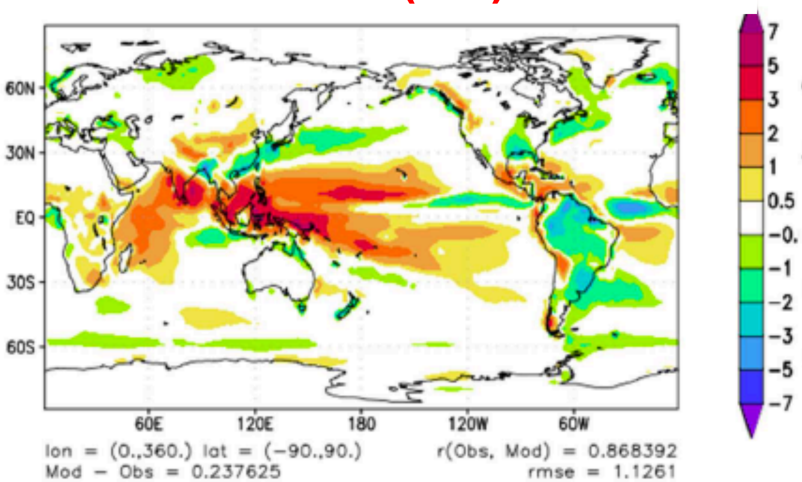
- **Global-mean precip. biased high compared to GPCP, common to GCMs;**
- **Tightly controlled by atmospheric energy balance, thus hard to change in the model.**
- **How reliable is GPCP?**

Regional biases (mm day^{-1})

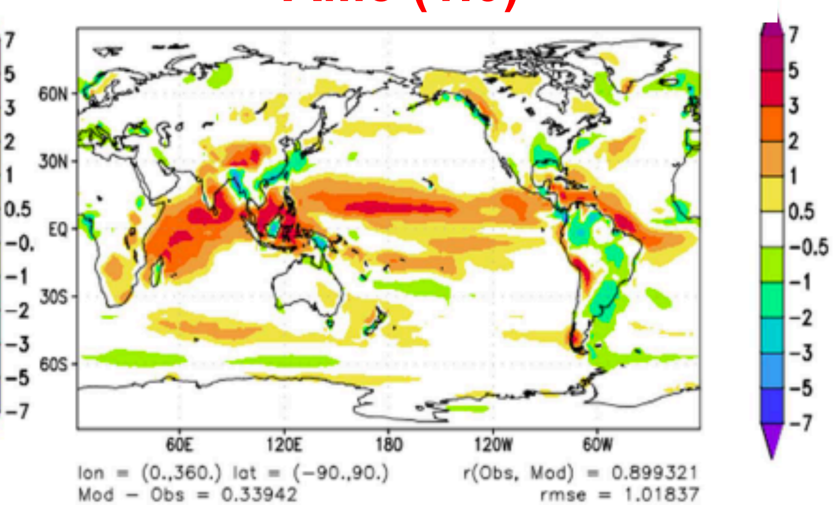
AM4 (0.84)



AM2 (1.1)

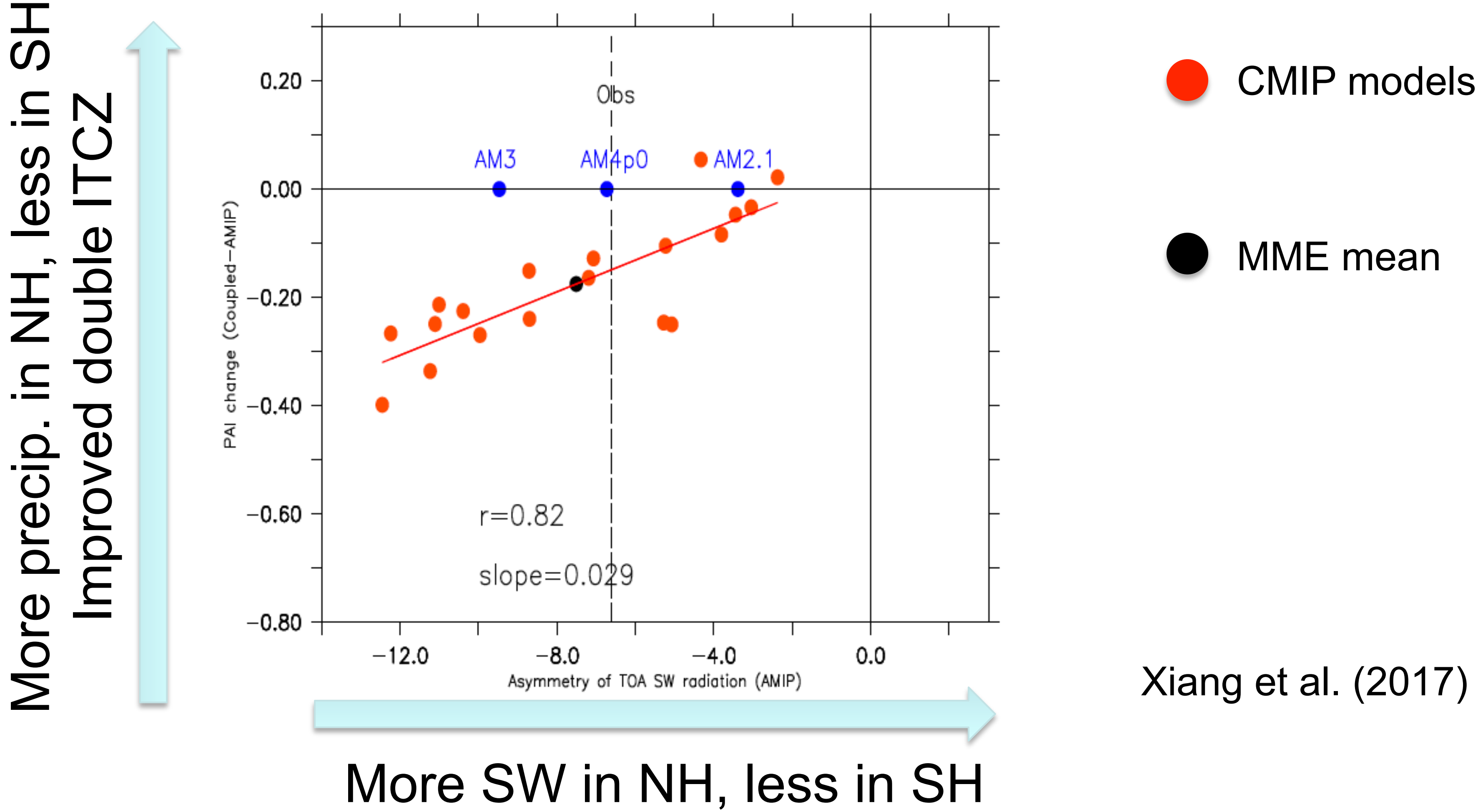


AM3 (1.0)



- **Largest biases over ITCZ and SPCZ;**
- **Improved "double ITCZ", but not a good predictor of coupled model performance.**

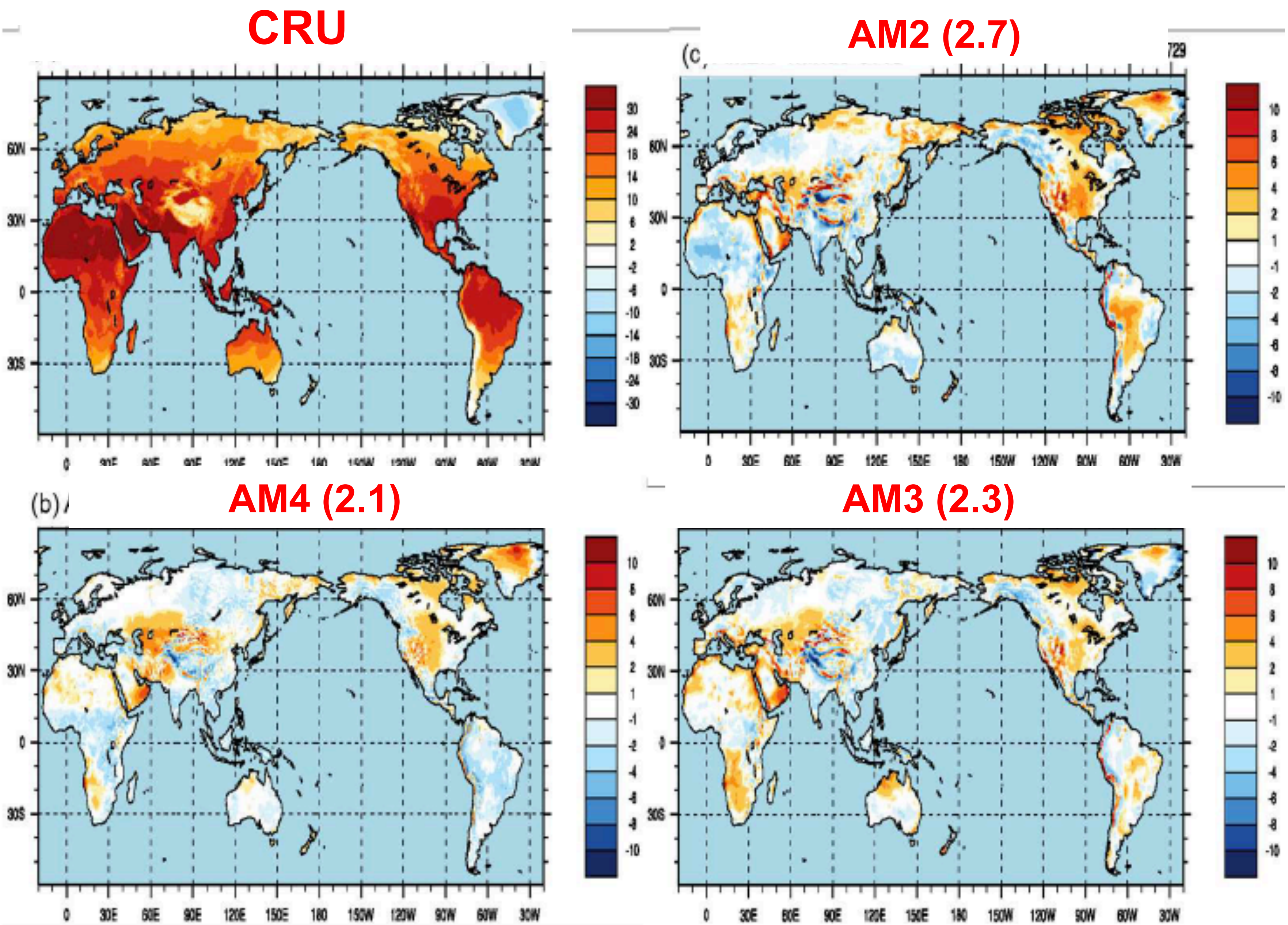
<u>Double ITCZ</u> in coupled models (CM) linked to <u>hemispheric asymmetry in TOA SW radiation</u> in atmospheric models (AM)



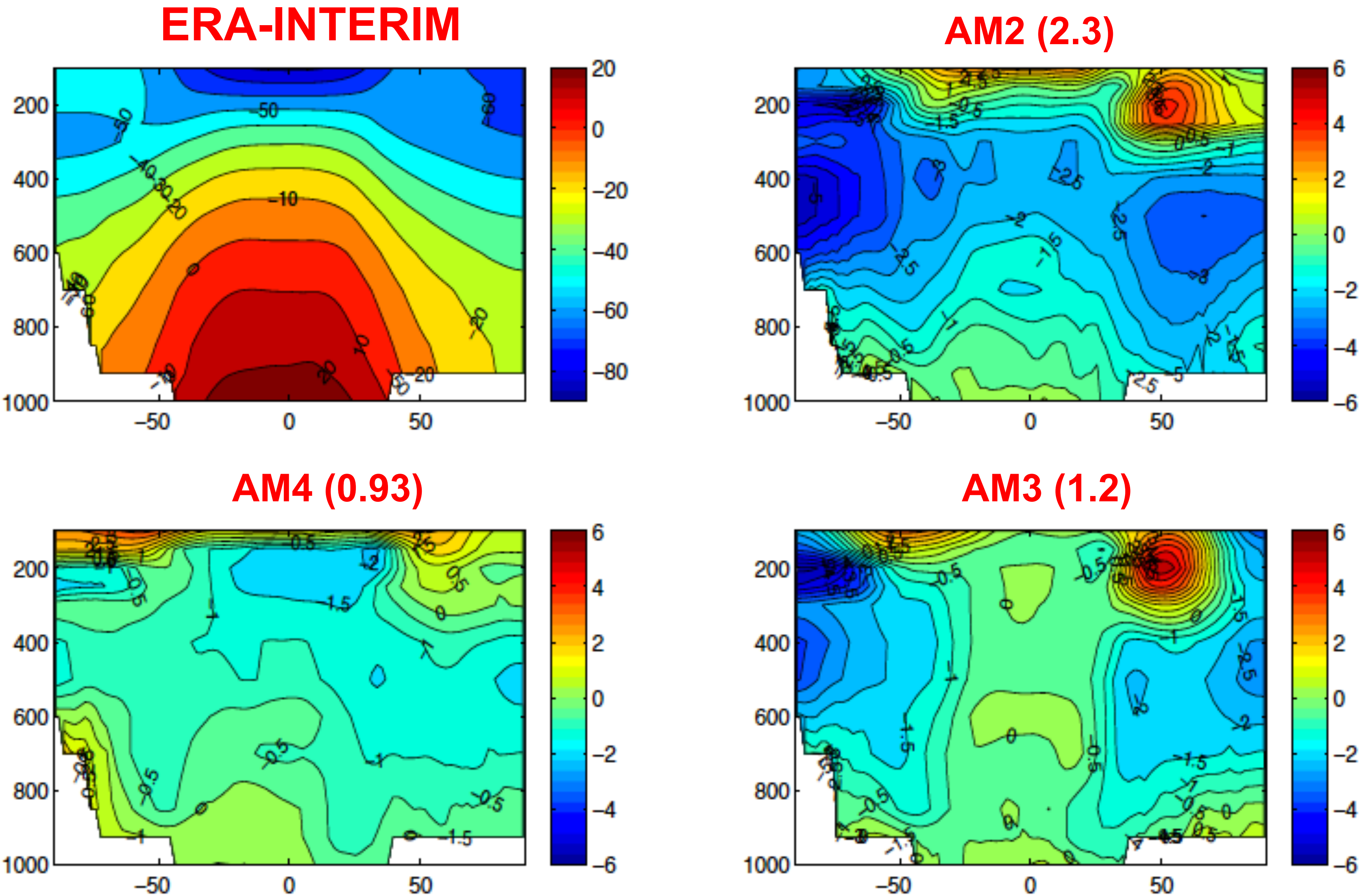
Xiang et al. (2017)

Conundrum: The good TOA SW radiation in AM4 is not expected to improve double ITCZ due to compensating errors.

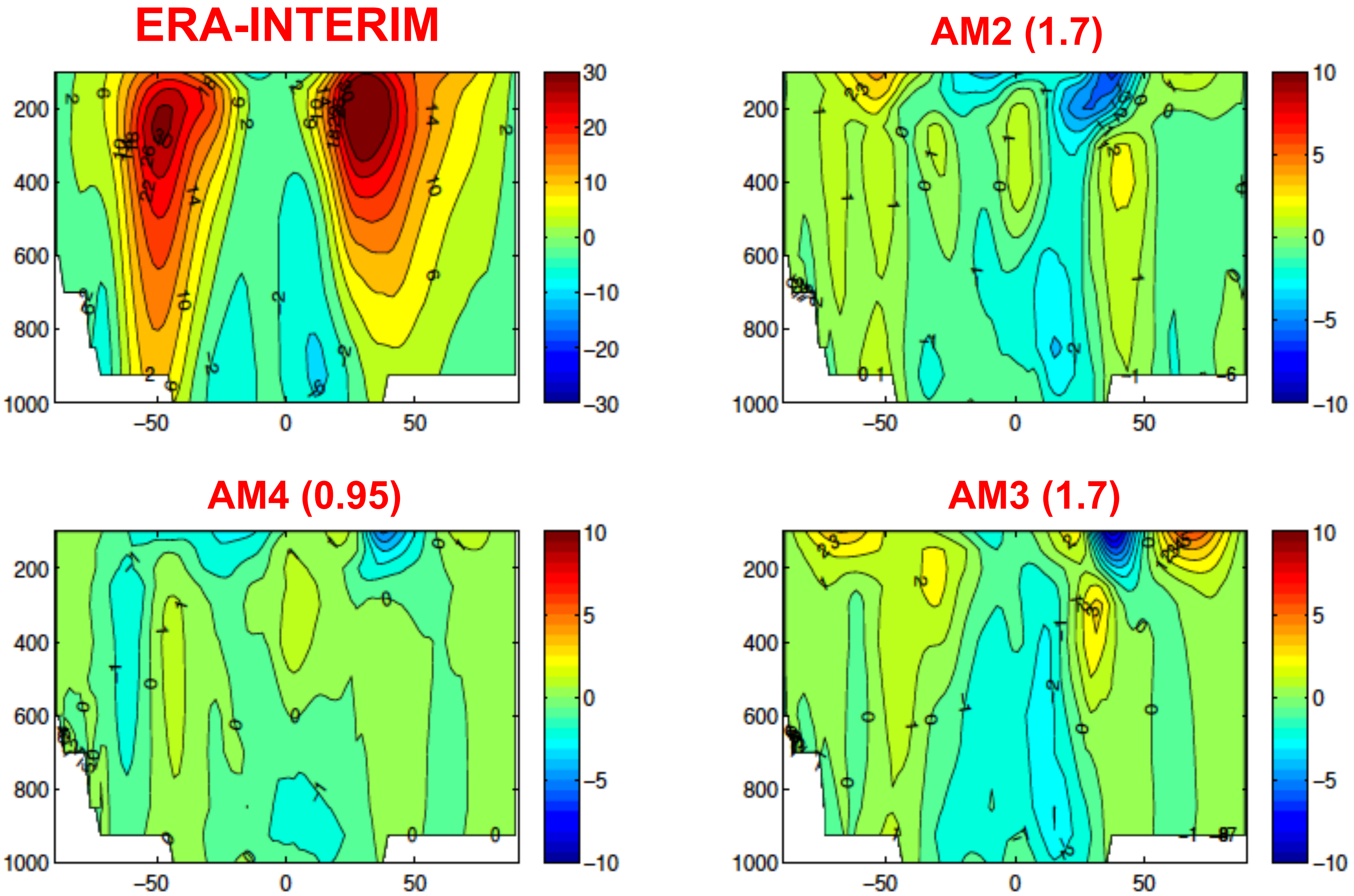
DJF 2-m temperature (°C)



DJF atmospheric temperature (°C)



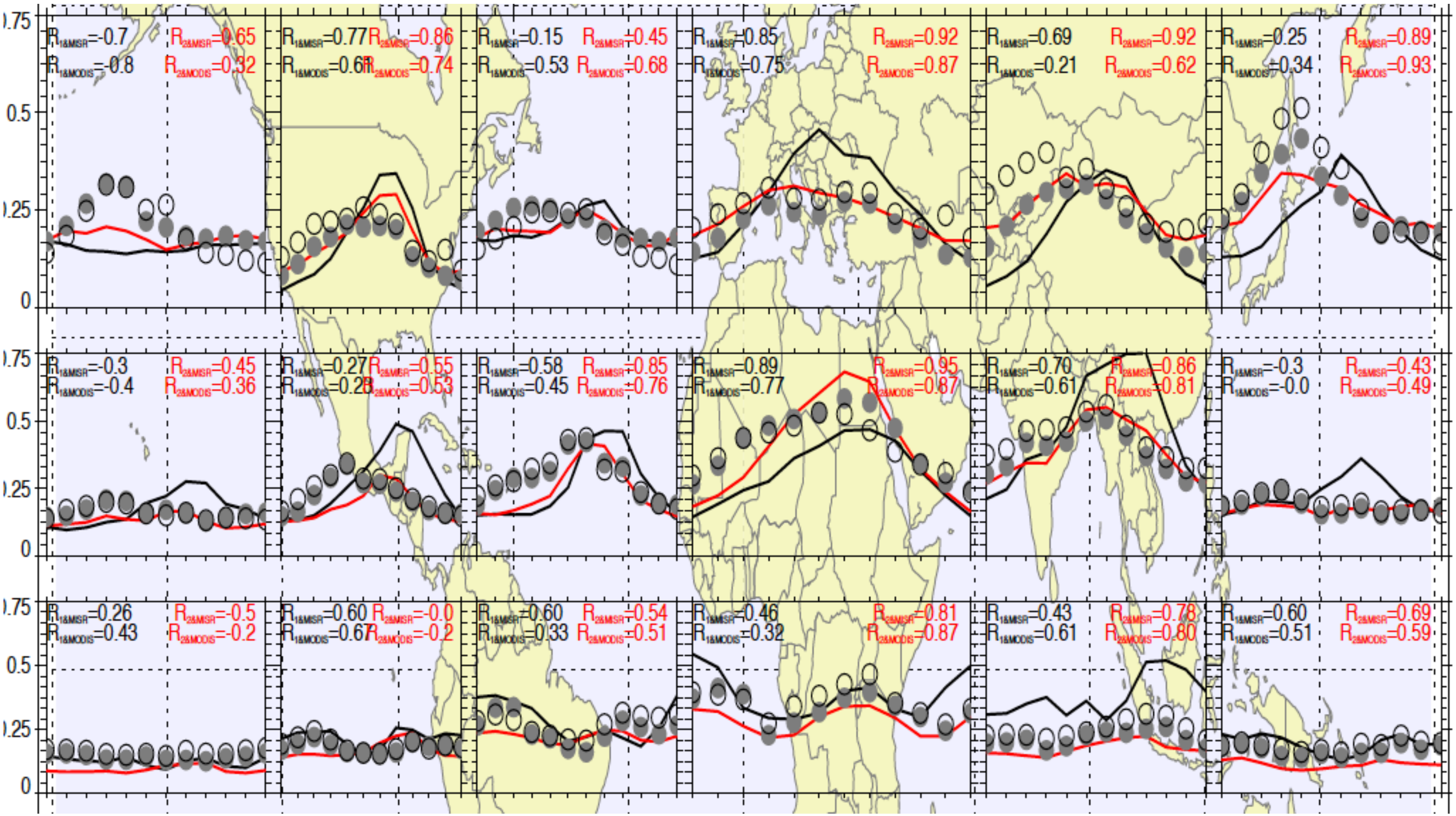
DJF zonal wind (m s^{-1})



Aerosol optical depth

AM4: red lines AM3: black lines

MODIS: filled circles MISR: open circles

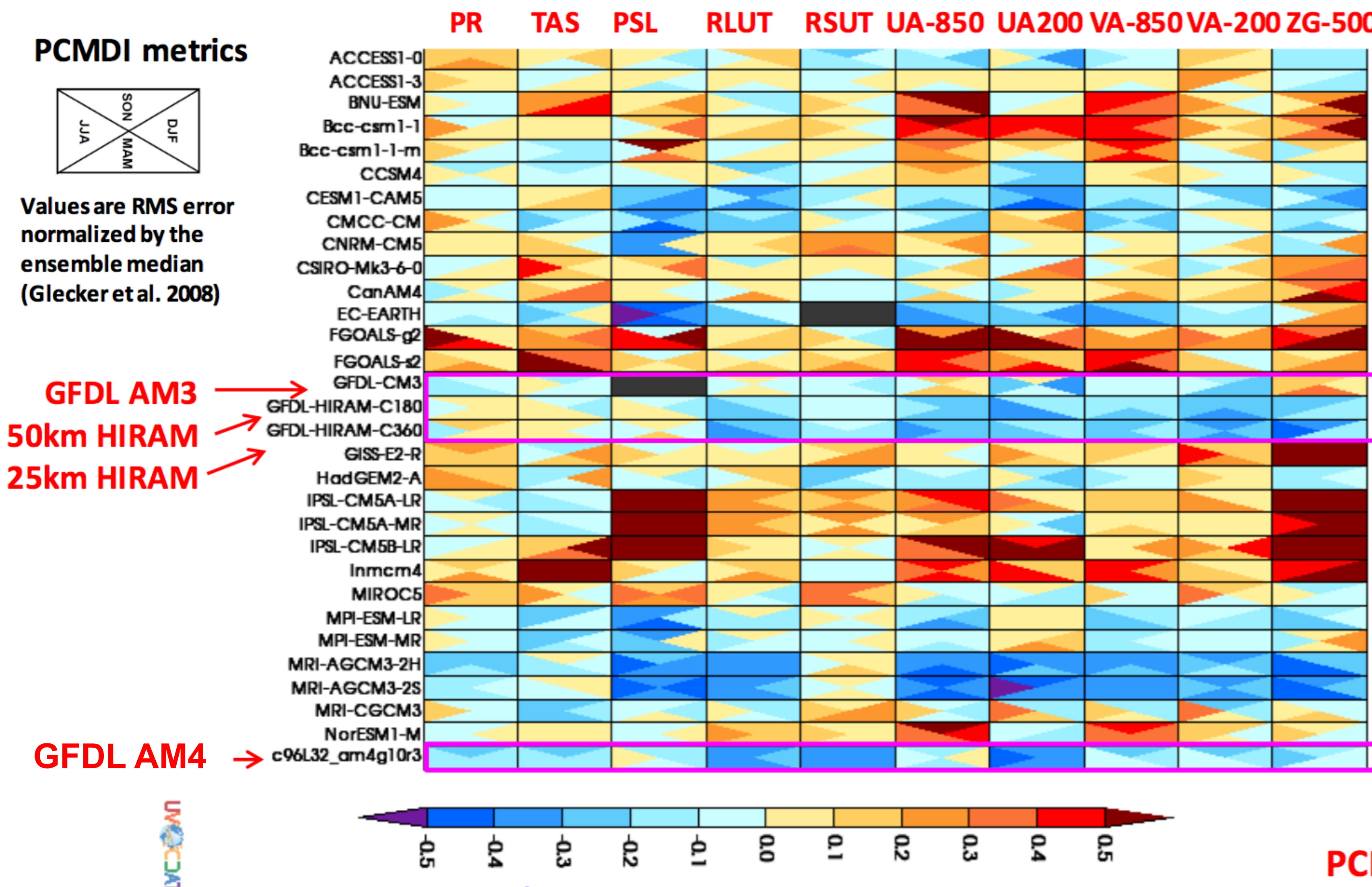


Comparison with CMIP5 atmospheric models

PR: Precipitation; TAS: Surface air temperature; PSL: Sea-level pressure; RLUT: Outgoing LW radiation; RSUT: reflected SW radiation at TOA; UA-850 & UA200: 850 and 200hPa zonal wind; VA-850 & VA-200: 850 and 200hPa meridional wind; ZG-500: 500hPa geopotential height.

PCMDI metrics

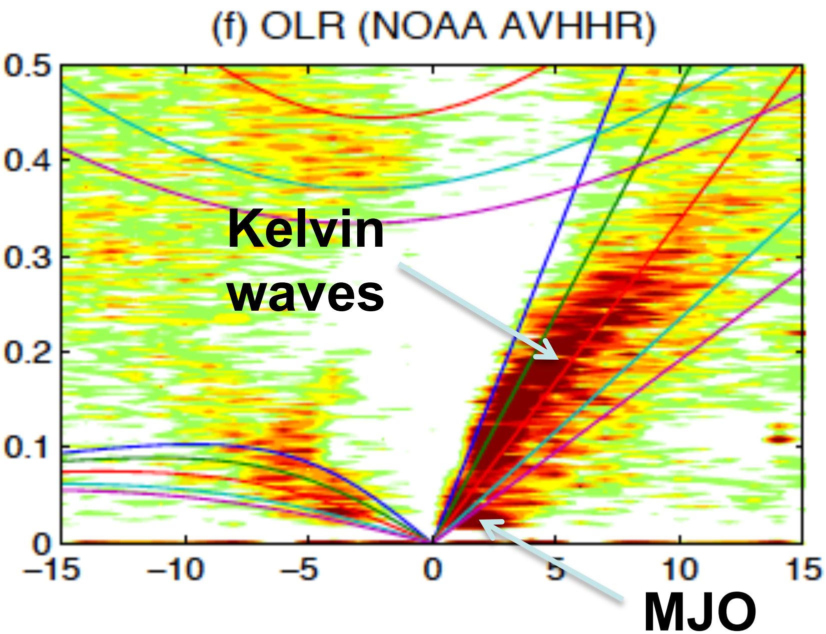
Values are RMS error normalized by the ensemble median (Glecker et al. 2008)

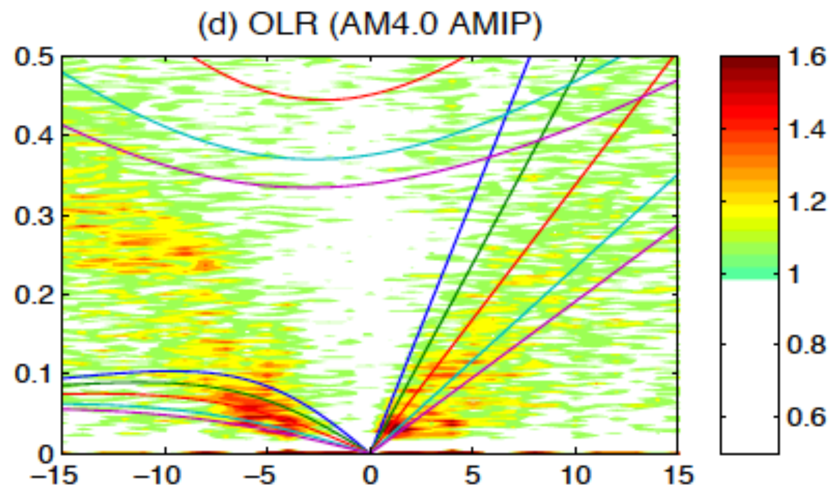


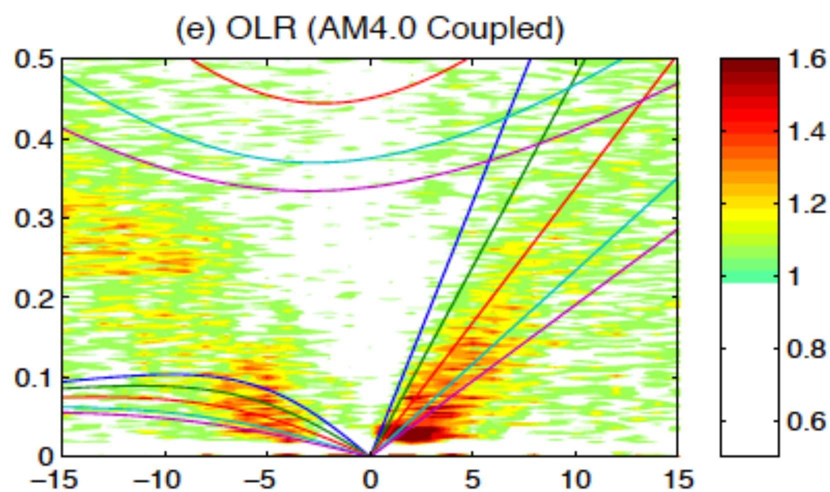
PCMDI Portrait Plot

Tropical variability

Normalized tropical symmetric OLR wavenumber -frequency power spectrum

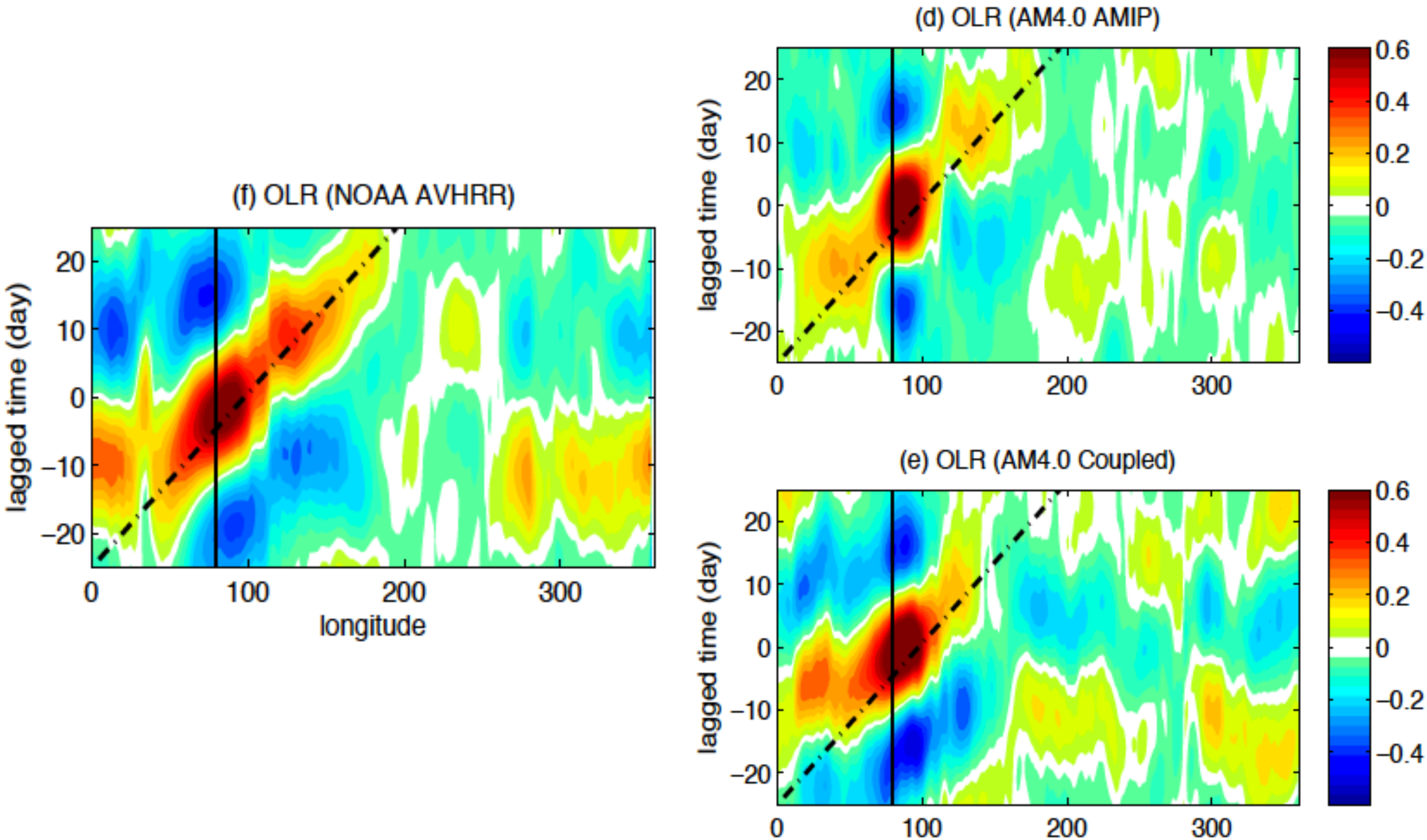




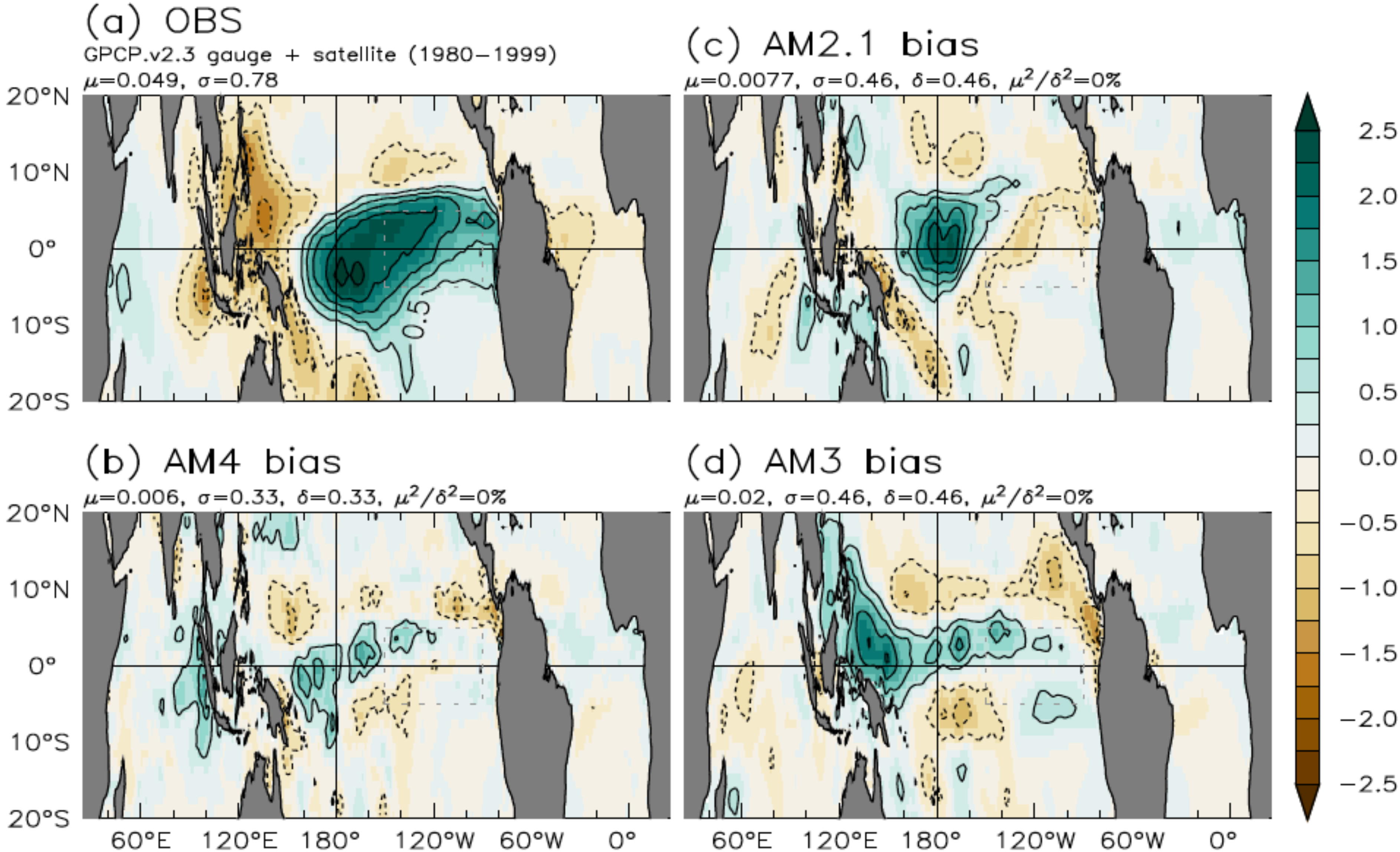


Good MJO, but weak Kelvin waves;
Coupling is important for MJO.

Lag correlation in OLR anomalies between Indian Ocean and all longitudes

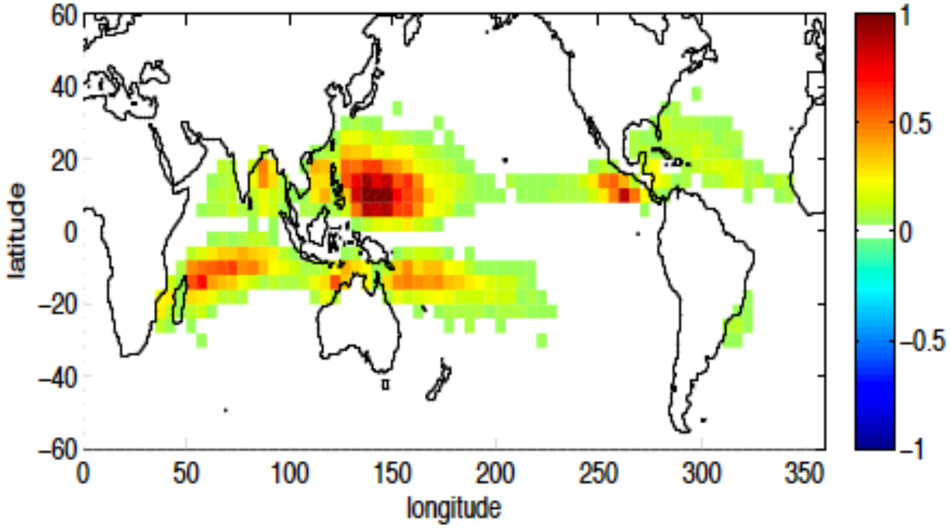


Rainfall (mm day^{-1}) regress onto NINO3 SST (K)

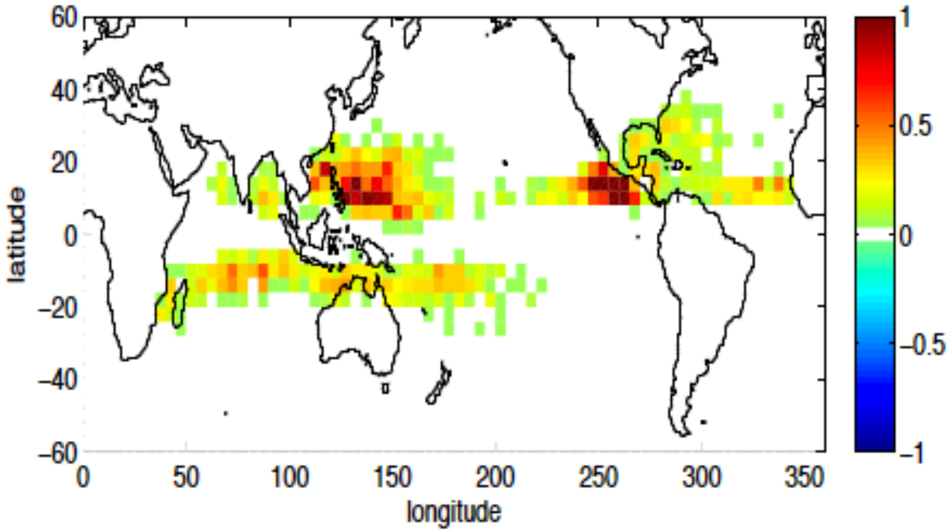


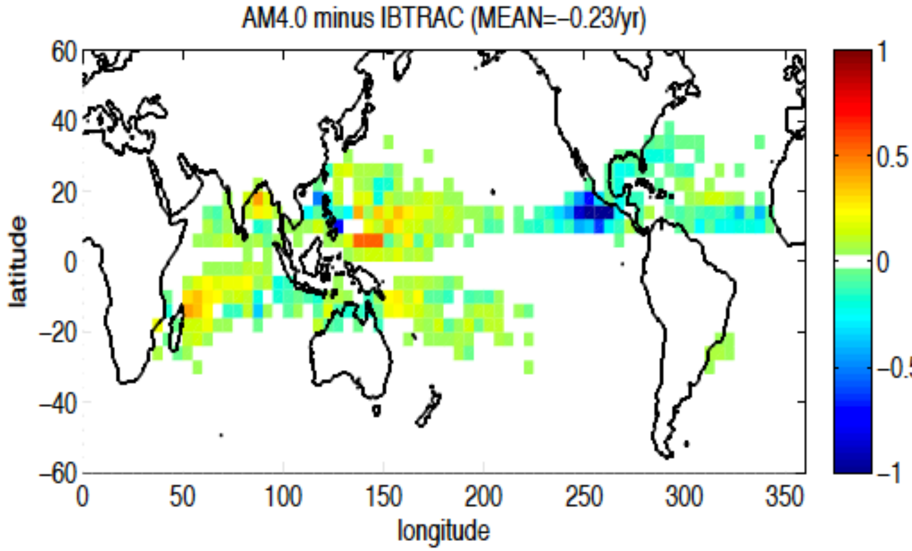
Tropical cyclones genesis

AM4 (79.5 $year^{-1}$)

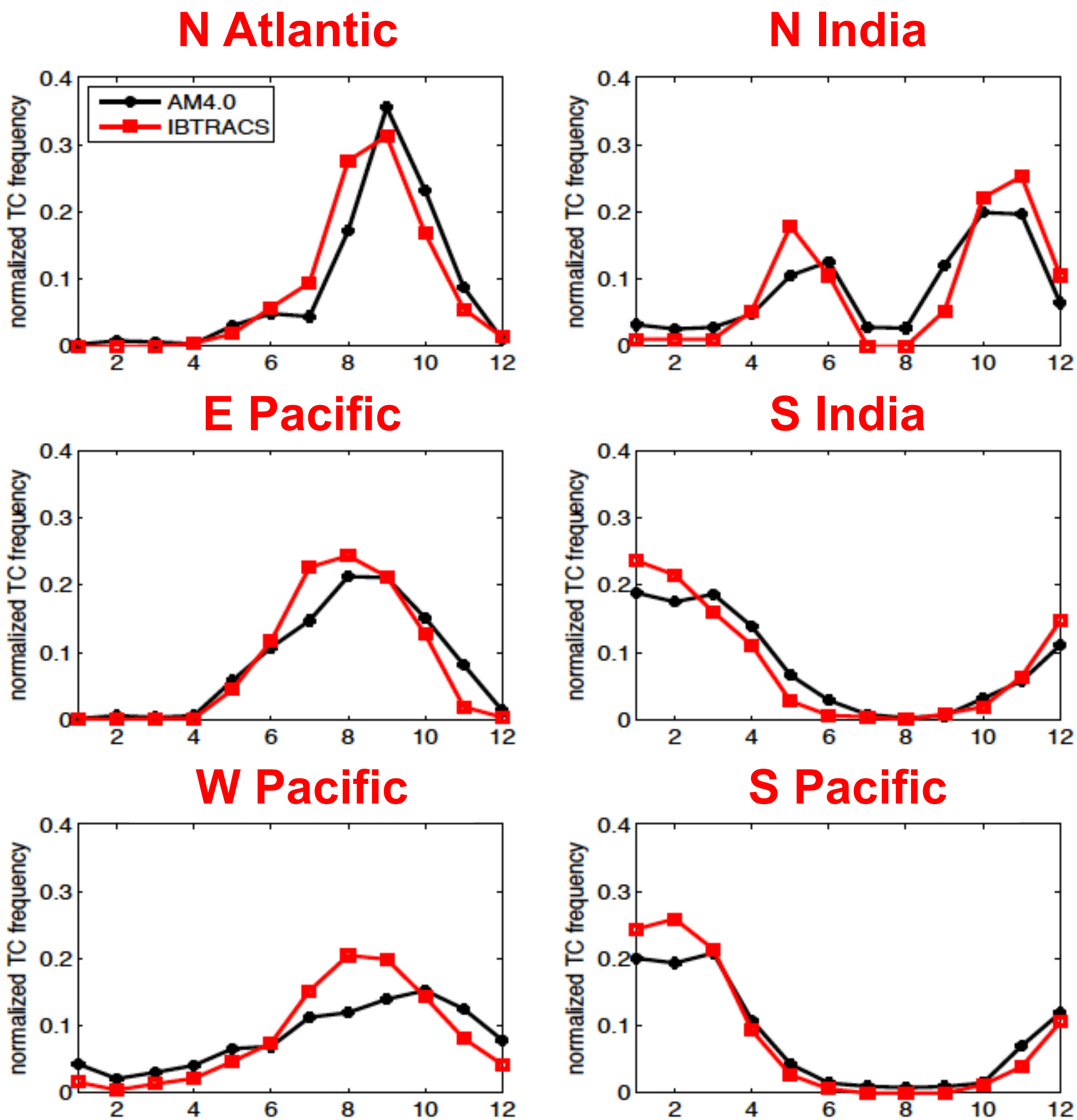


OBS (79.7 $year^{-1}$)



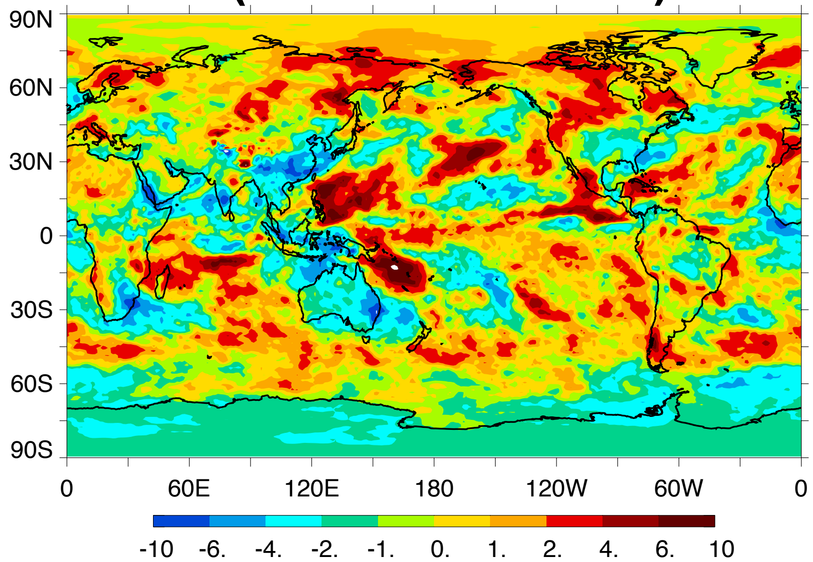


Seasonal cycle of TC frequency over different basins

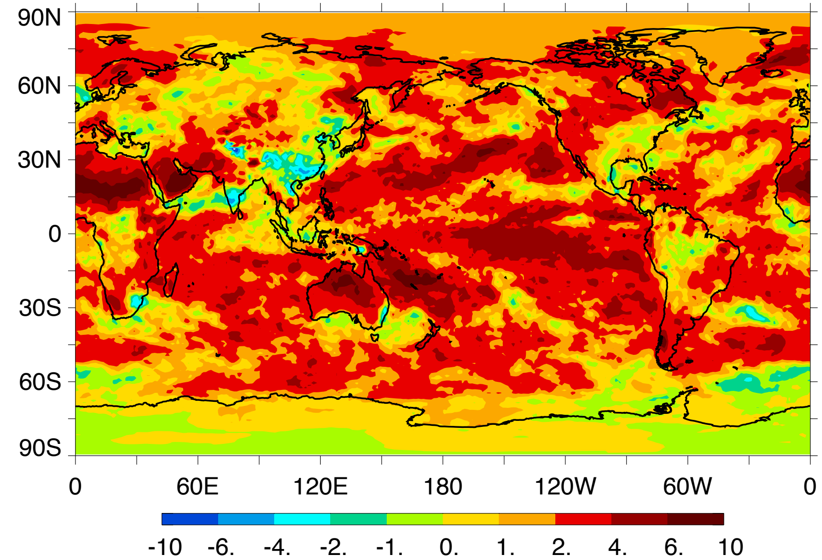


Aerosol forcing (W m^{-2})

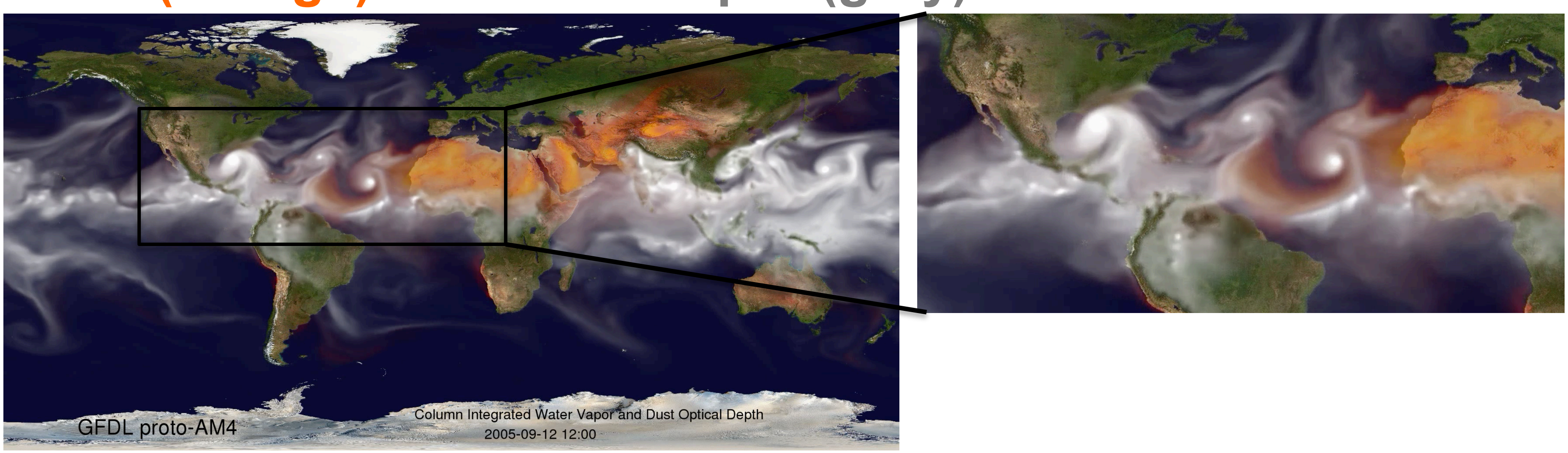
Aerosol (direct & indirect) -0.7



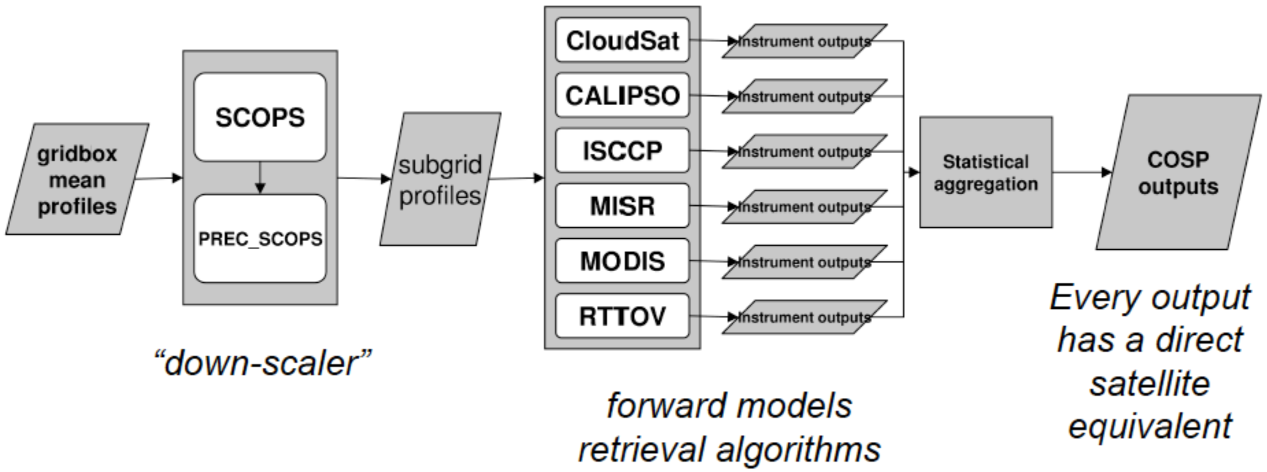
Aerosol & WMGG 2.1



Dust (orange) and water vapor (grey)



Use of Satellite Simulator at GFDL

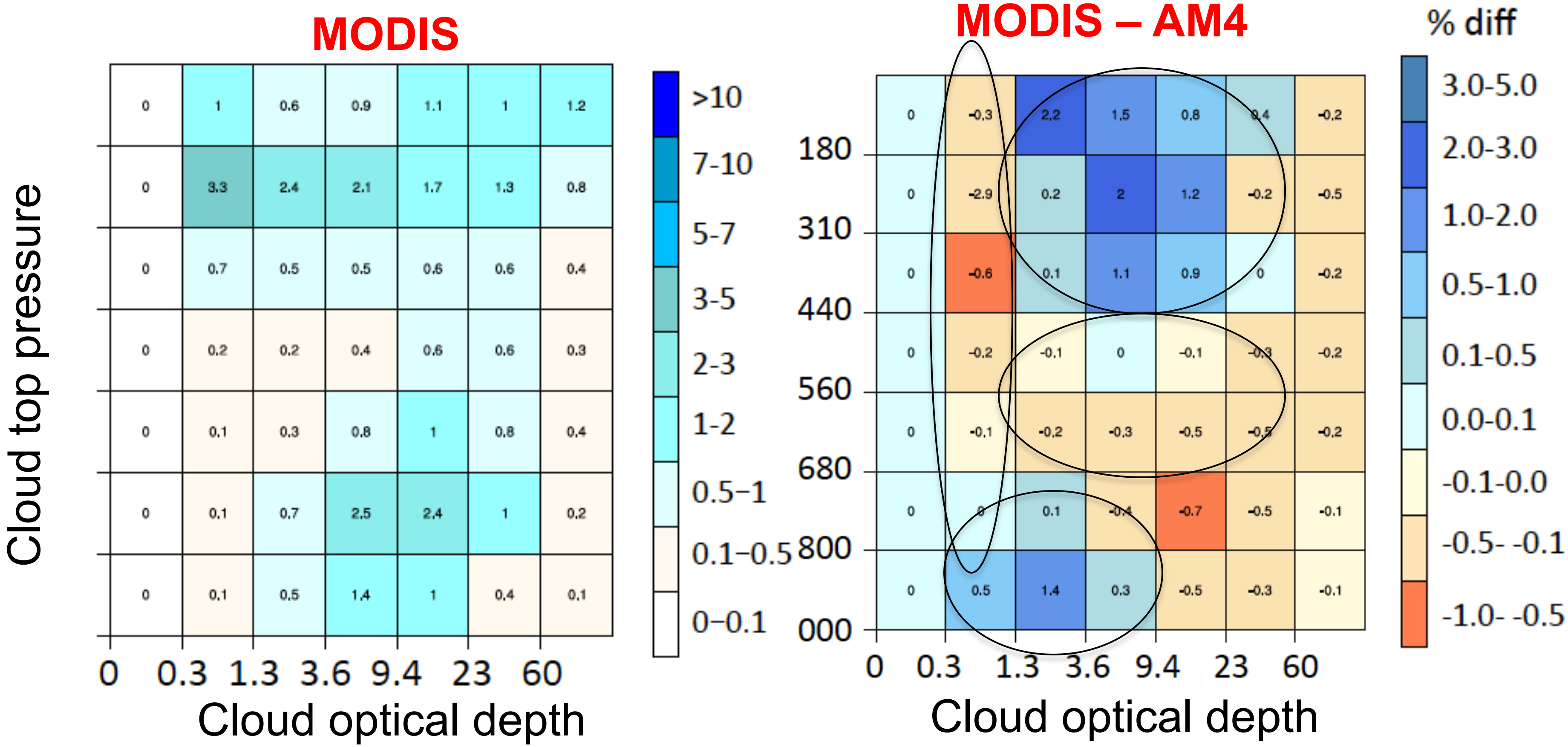


For more information about COSP, see Steve Klein's CERES talk (https://ceres.larc.nasa.gov/documents/STM/2011-10/13_klien.ceres11.talk.pdf).

- The latest version of COSP (Cloud Feedback Model Intercomparison Project Observation Simulator Package) has been implemented in AM4.
- The COSP-derived model fields compare better with satellite data than direct outputs, yielding insights into model biases.
  - ❖ Joint histogram of cloud top pressure/optical depth
- Yet, challenges remain on both sides
  - ◆ Hard to translate COSP diagnostics to the process/parameterization level.
  - ◆ Long way to go to reconcile the different cloud microphysical assumptions.
    - ❖ Liquid cloud effective radius

Credit: Levi Silvers

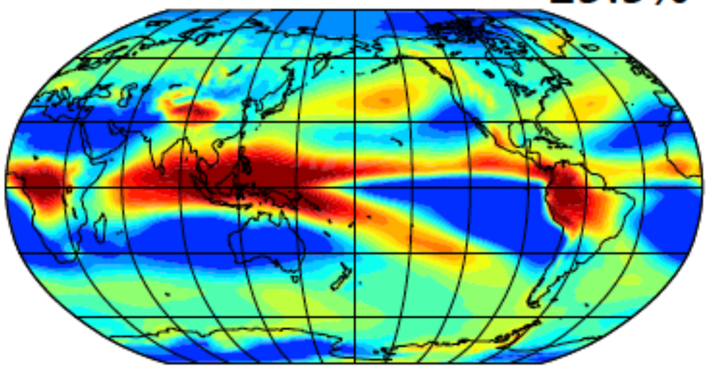
Joint histogram of cloud top pressure and optical depth for tropical clouds



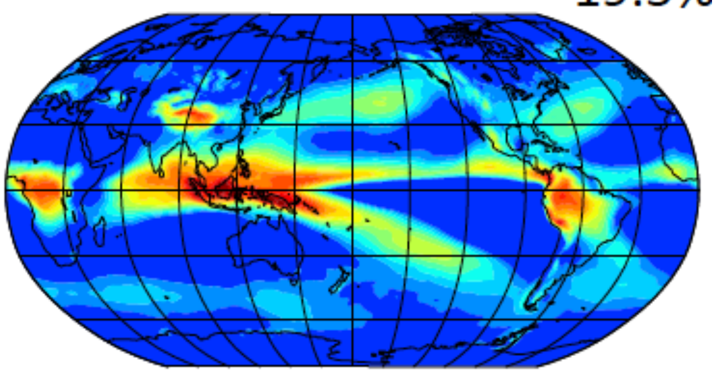
- **Too few high clouds, but too many middle clouds (contrary to the conventional wisdom);**
- **Too few low clouds (as always);**
- **Too many optically thin clouds (is this really the case?);**

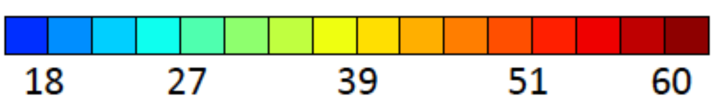
Discrepancy in high cloud amount between MODIS and CALIPSO

AM4 (CALIPSO) 29.9%

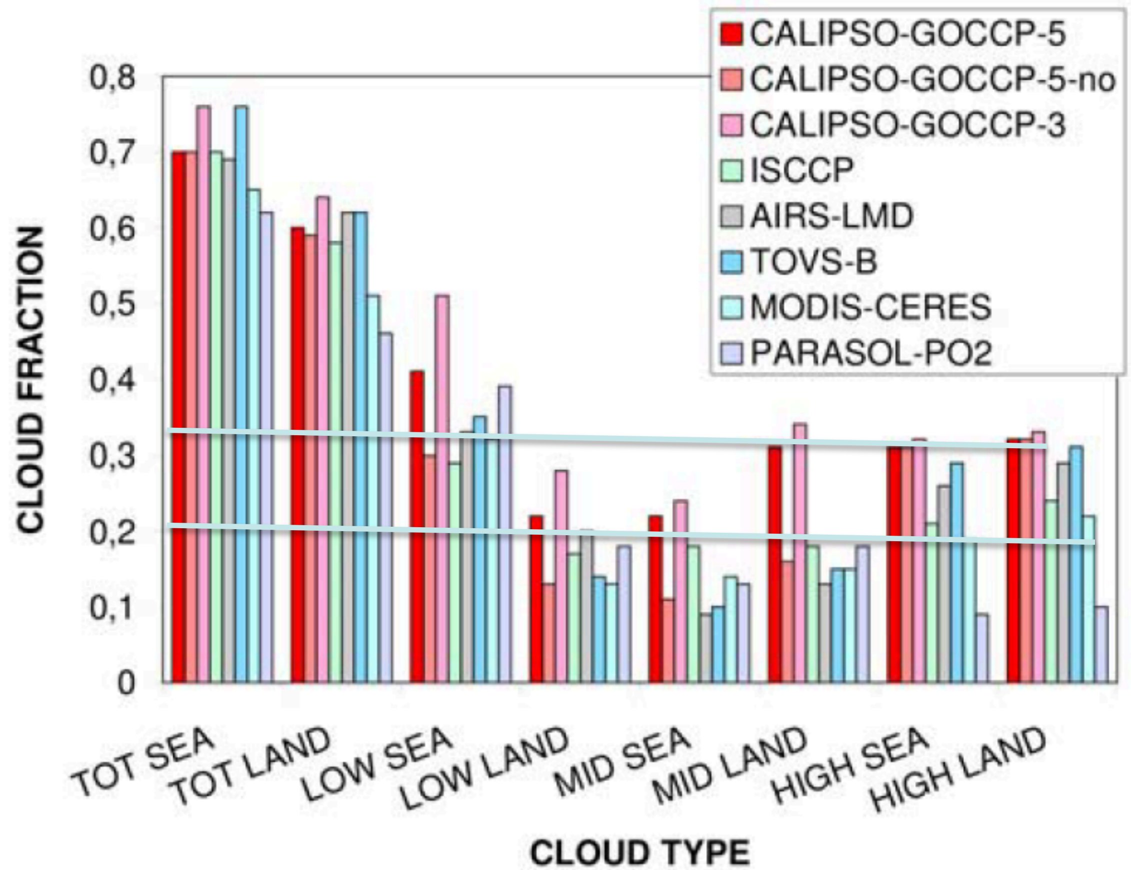


AM4 (MODIS) 19.5%





MODIS high cloud amount: 20%
Marchand et al. (2010)



Chepfer et al. (2010)

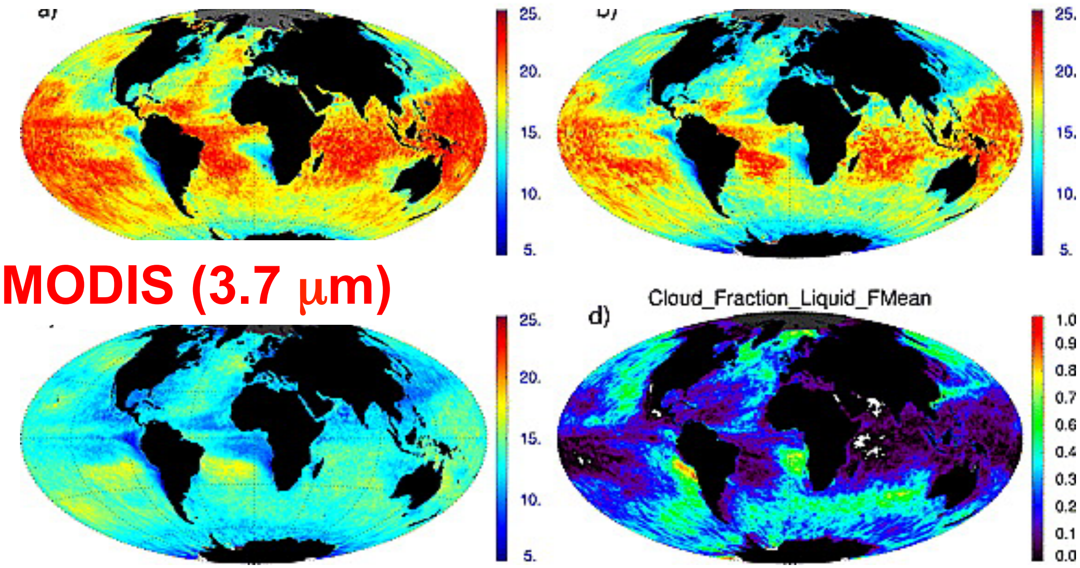
- **LIDAR is more sensitive to thin cirrus;**
- **AM4 is right on the mark.**

Liquid cloud effective radius (μm)

MODIS (1.6 μm)

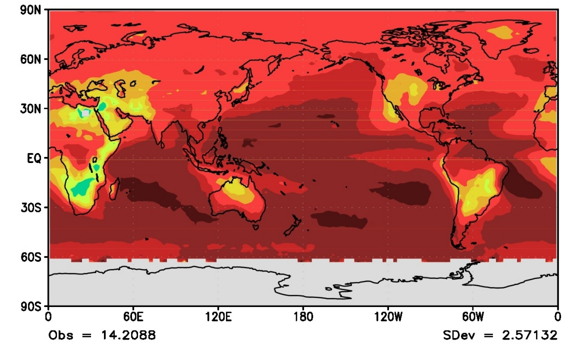
MODIS (2.1 μm)

MODIS (3.7 μm)

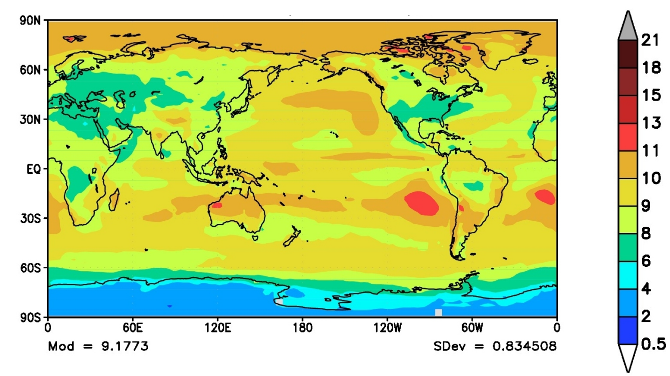


Zhang and Platnick (2011)

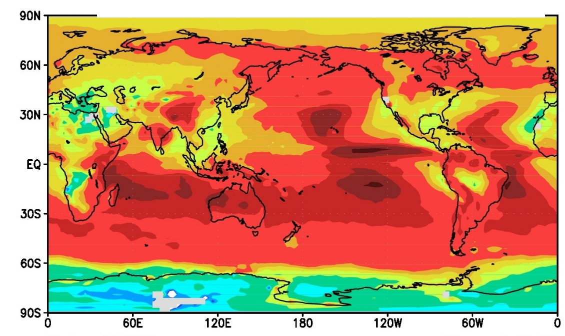
MODIS (3.7 μm)

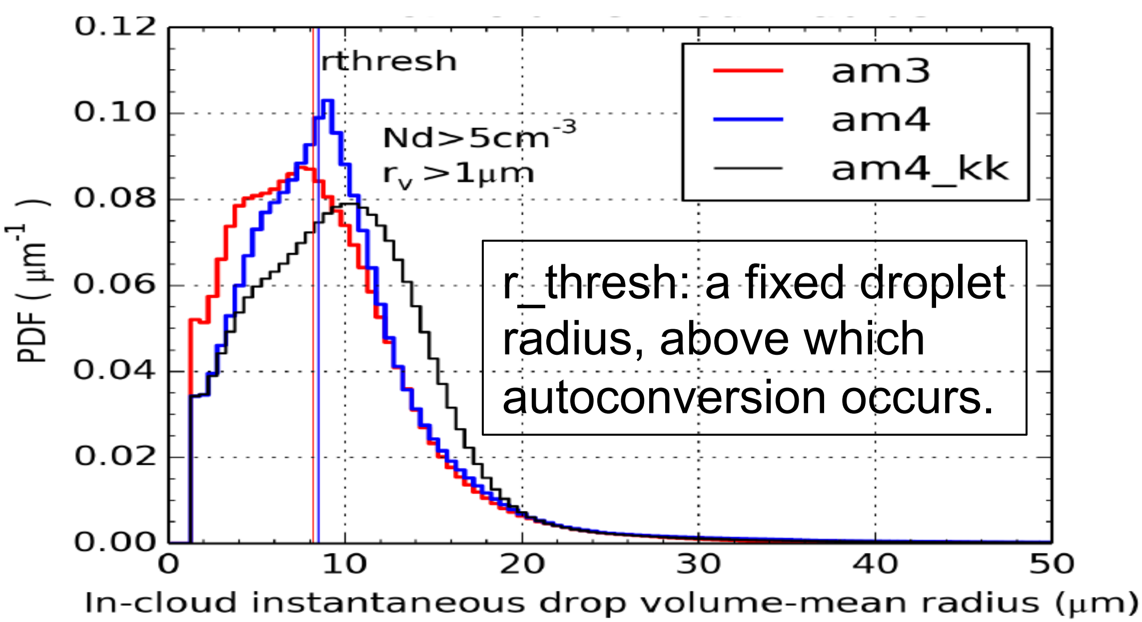


AM4



AM3

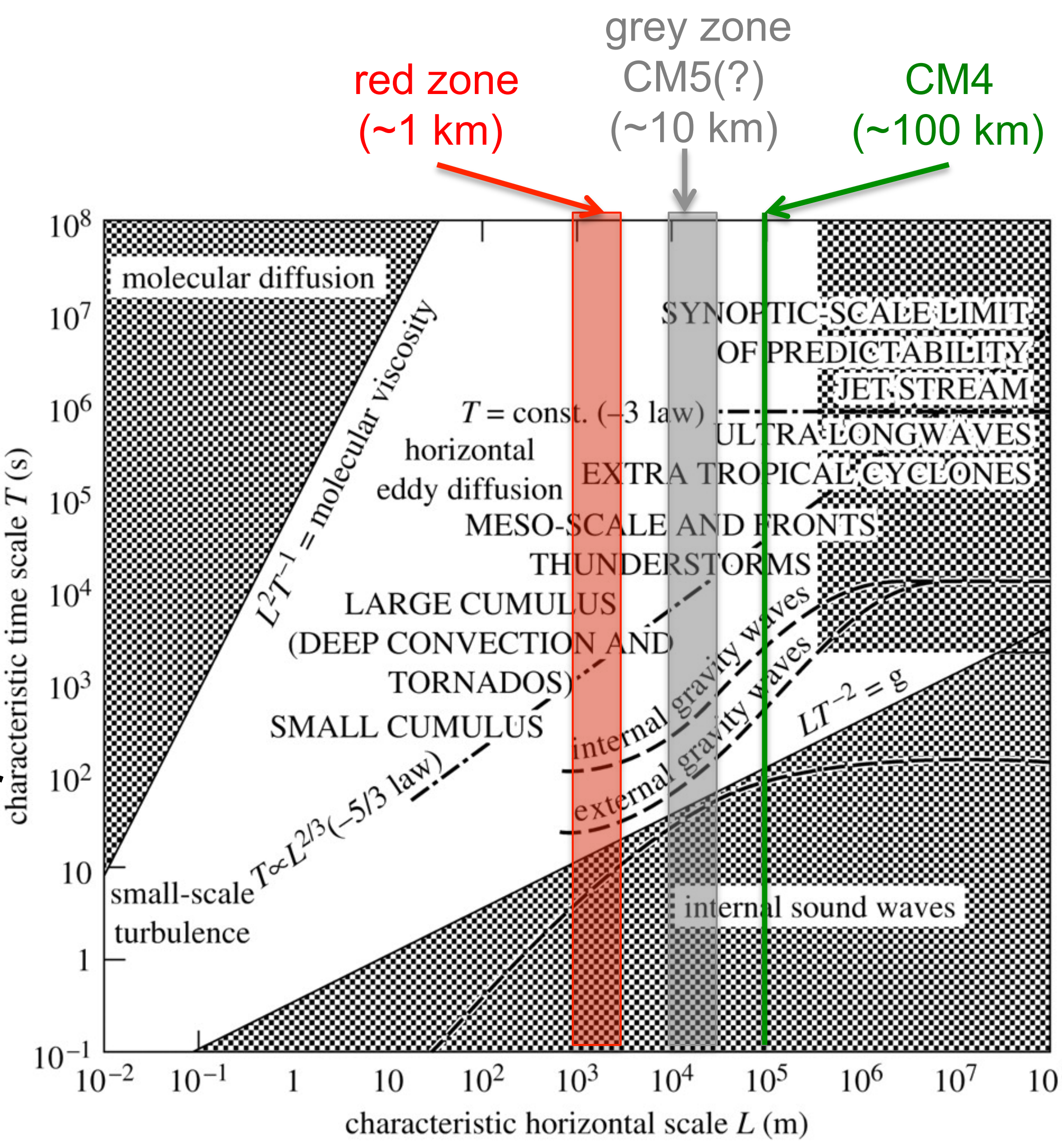




r_thresh: a fixed droplet radius, above which autoconversion occurs.

Exploring atmospheric physics in the "grey zone" (tens of km)

- **Partially resolved deep convection ("cloud permitting")**
- **Need for re-evaluating existing parameterizations (developed for coarse resolution, resolution-dependence)**
- **Push to the "red zone" (a few km, "cloud resolving") for short (days to months) runs as learning tools**
- **A hierarchy of models (e.g., LES, RCE with regional CRM or GCM physics, high-end global CRM)**
- **Use of simulations, augmented by evaluation and process-level diagnostics, for guiding parameterization development.**

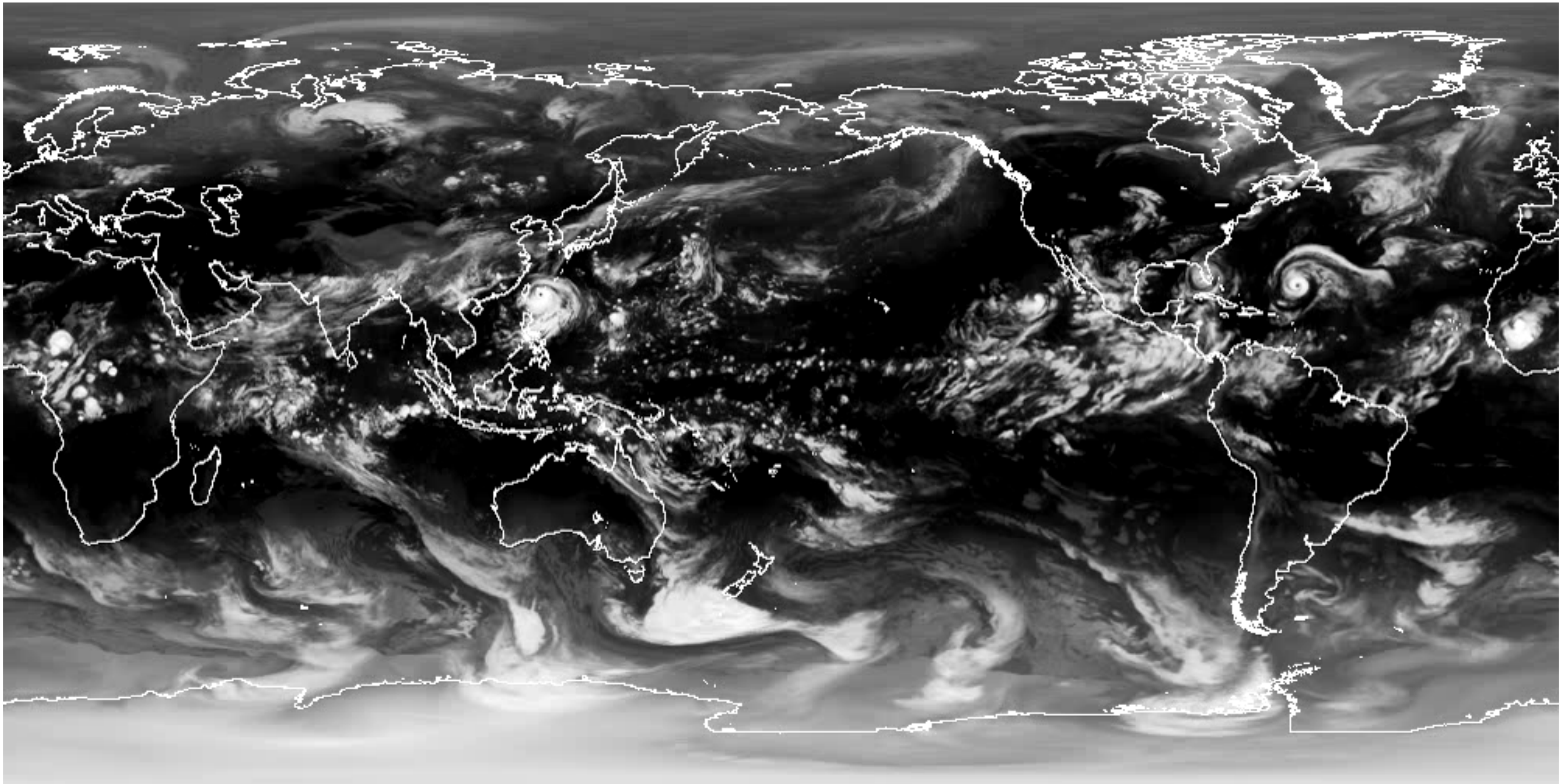


Going back to the NWP root!

Following Smagorinsky (1974)

Weather-climate model simulations

Example 1: Global "cloud-permitting" models (~3.5 km)



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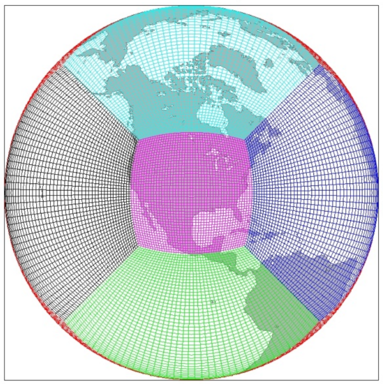
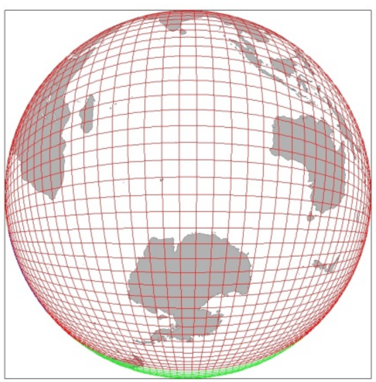
Example 2: Global *regional* cloud-resolving models enabled by grid stretching and nesting (e.g., ~1 km over CONUS)

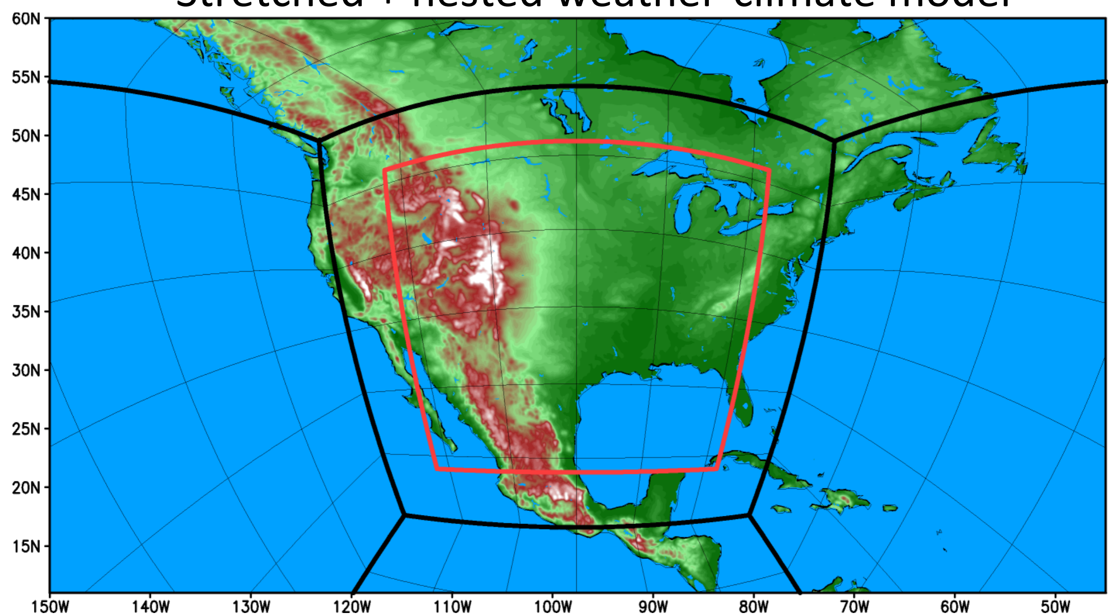
Oklahoma City

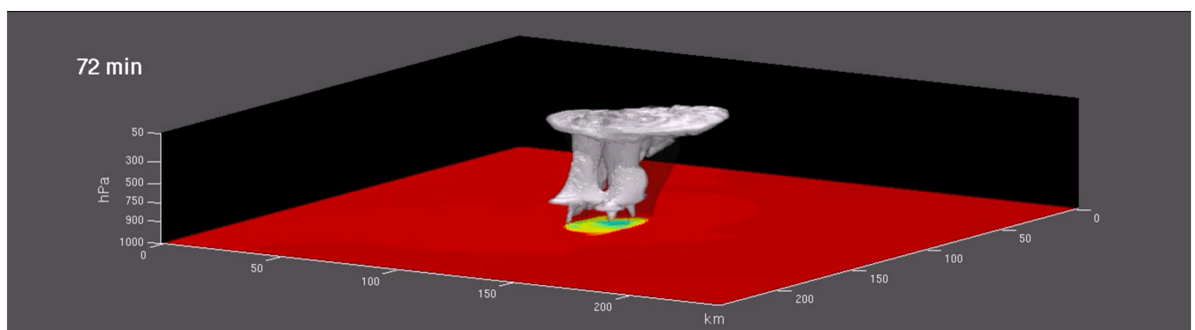


Back side of OKC



Stretched + nested weather-climate model





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Conclusions

- CM4 shows considerable skills in simulating mean climate and tropical variability;
- Satellite products, CERES in particular, are crucial for model development. More synergy between them can be harnessed;
- Despite many real challenges, we are excited about **all the new sciences and applications that the high-end weather/climate modeling at GFDL will enable** for many years to come**.**

Model evaluation and diagnostics

- **Short (days to months) simulations in weather forecast or seasonal prediction mode [as efficient ways to expose model biases]**
- **Process-level diagnostics (moist convection, MJO, mid-latitude cyclones, ...) [spearheaded by the NOAA/ CPO Model Diagnostics Task Force]**
- **Comparison with observations (CloudSat, …)**
- **Idealized experiments (aquaplanet, COOKIE, …)**
- **Community-wide efforts (CPT, CFMIP, …)**
- **…**

Goal: Development of physics parameterizations applicable to weather-climate models